Smart Village E-Governance System for Transparent Sabha Management

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Abstract--- The GramBox X IoT Voting and Governance System is an innovative rural-centric digital governance solution designed to promote transparency, inclusivity, and participation in Gram Sabha decision-making processes. The system integrates ESP32, LCD display, DFPlayer Mini, SD card module, and voting buttons to enable villagers to cast their votes on local proposals without the need for internet connectivity. Each proposal is displayed on an LCD screen and simultaneously announced through Tamil voice assistance to ensure accessibility for all citizens, including those with limited literacy. Votes are recorded securely in text files on the SD card, allowing for offline storage and later retrieval by administrators. The hardware-software integration ensures reliable performance through debounce logic, accurate vote logging, and modular data handling. By utilizing low-cost components and solar power compatibility, the system provides a scalable and sustainable approach to e-governance in remote rural areas. GramBox X demonstrates how IoT technology can bridge the digital divide by transforming traditional community meetings into data-driven, transparent, and participatory governance platforms. This project contributes to the realization of Smart Village initiatives and serves as a model for future expansions such as SMS-based notifications, biometric authentication, and offline grievance recording.

Keywords—GramBox X, IoT, ESP32, DF Player Mini, LCD Display, SD Card Module, Rural E-Governance, Smart Village, Tamil Voice Assistance, Offline Voting System, Digital Participation, Sustainable Development

I. INTRODUCTION

Rural governance plays a crucial role in the development of villages and the implementation of welfare schemes through Gram Sabhas—the cornerstone of India's democratic decision-making at the village level. However, many Gram Sabha meetings face challenges such as low participation, lack of transparency, and manual record-keeping. These issues often result in limited community involvement and inefficiency in project approvals. The GramBox X IoT Voting and Governance System aims to digitalize the Gram Sabha process by introducing a simple, low-cost, and accessible electronic voting mechanism. The system is designed using an ESP32 microcontroller, integrated with a DF Player Mini, I2C LCD display, SD card module, and voting buttons. Villagers can view proposals on the LCD screen, listen to Tamil voice guidance through the speaker, and cast their votes by pressing the YES or NO buttons. Votes are recorded in the SD card as text files, eliminating the need for real-time internet connectivity and ensuring secure offline data storage. This IoT-based solution enhances transparency, accuracy, and inclusivity in local governance. It also bridges the digital divide by enabling participation from all sections of society, including those with limited literacy. The use of voice assistance in regional language and solar power compatibility ensures that the system is both user-friendly and sustainable. By integrating smart technology with rural administration, GramBox X transforms traditional Gram Sabha voting into a transparent, efficient, and accountable process. It lays the foundation for smart village development, where IoT-based automation supports e-governance, local data management, and community empowerment.

II. SYSTEM DESIGN

A .Overview of the System Design

The GramBox X IoT Voting and Governance System is designed to facilitate transparent and accessible voting in Gram Sabha meetings using embedded IoT technology. The system operates completely offline, powered by an ESP32 microcontroller that controls all connected modules including the LCD display, DFPlayer Mini, SD card module, and voting buttons. Each component plays a vital role in ensuring seamless interaction and data reliability during the voting process.

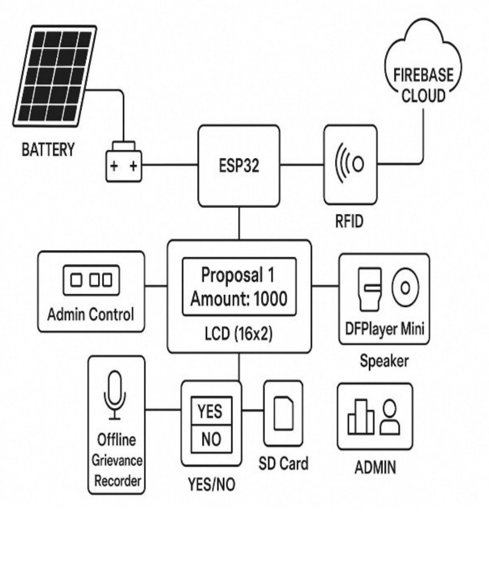

Fig 1

The ESP32 acts as the core processing unit, reading proposal details from the SD card and displaying them on a 16x2 LCD. The DFPlayer Mini module provides Tamil audio announcements, guiding villagers through each voting step. The user can then cast a vote by pressing either the YES or NO button, and the ESP32 logs the result to the SD card as a text entry for later analysis. This design combines the simplicity of embedded hardware with the practicality of voice-based assistance, creating an inclusive and transparent system that does not depend on external servers or internet connectivity. The system's modular design allows future integration of features such as admin dashboards, GSM-based alerts, and biometric authentication.

B. Hardware Configuration

The Embedded Main Board Module is the core functional unit of the GramBox X IoT Voting and Governance System. It integrates all electronic components on a single platform, enabling communication, control, and coordination between the hardware devices. The heart of the module is the ESP32 microcontroller, which manages all data processing, logic execution, and input–output operations. The ESP32's built-in Wi-Fi and Bluetooth capabilities allow for future scalability, while its multiple GPIO pins support the simultaneous interfacing of the LCD display, SD card module, DFPlayer Mini, and voting buttons.

The module is designed on a compact embedded board that provides stable power distribution and secure connections for all peripherals. The I2C interface connects the 16x2 LCD display for proposal visualization, while the SPI interface links the SD card module used for storing proposal and voting data. The DFPlayer Mini communicates with the ESP32 via serial communication to play pre-recorded Tamil voice messages from its SD card, ensuring accessibility for all users. The two voting buttons are configured as digital inputs with internal pull-up resistors, connected directly to the ESP32 for reliable detection of YES and NO responses.

To ensure smooth operation, the embedded main board includes debounce logic for button inputs and error handling for SD card read–write operations. The power supply section is designed to deliver regulated 5V and 3.3V outputs to support all components, with common grounding to maintain signal integrity. The system is capable of functioning either through a standard DC adapter or a solar-based supply, making it adaptable for use in remote rural locations.

Overall, the Embedded Main Board Module acts as the central nervous system of the GramBox X system. It executes the program logic, synchronizes the display, audio, and data storage functions, and ensures that every vote is recorded accurately. The modular nature of this design allows for easy maintenance and future expansion, including the addition of wireless connectivity, GSM-based notifications, or integration with cloud databases. Through this embedded framework, the GramBox X achieves a balance of efficiency, reliability, and accessibility, providing a sustainable digital governance solution for rural communities.

C. Base Station Module

The Base Station Module in the GramBox X IoT Voting and Governance System serves as the administrative control and data management unit responsible for monitoring, reviewing, and analyzing the voting outcomes collected from the embedded voting terminals. It functions as the central node that receives, stores, and displays the data recorded by the Embedded Main Board Module. The base station can be operated by village administrative officers or Gram Sabha coordinators to verify proposals, view voting results, and maintain transparency in decision-making processes.

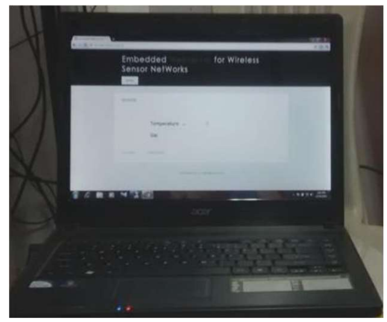

Fig. 3. Base Station PC

The module is built around an ESP32 or Raspberry Pi microcontroller platform that supports both offline and semi-online communication. Data from the SD card in the embedded voting module can be transferred to the base station through wired or wireless interfaces such as serial communication, Wi-Fi, or removable SD card exchange. The base station then processes this data to generate summary reports of votes cast for each proposal, including the total count of YES and NO responses. This ensures that results are securely consolidated and accessible only to authorized personnel.

A key feature of the Base Station Module is its ability to operate independently in areas without network infrastructure. The module can display voting results on an LCD or external monitor and can optionally export them to a local database or USB storage device for record-keeping. In enhanced versions, the base station can connect to a Firebase real-time database or a local web dashboard, allowing remote administrators to review voting statistics from multiple GramBox units deployed across different villages.

Power for the base station is supplied either through a regulated AC adapter or through solar power integration, ensuring uninterrupted functionality during Gram Sabha sessions. The design emphasizes security, data integrity, and ease of use, enabling rural administrative officers to handle digital voting records without requiring advanced technical expertise.

III. Hardware Requirements

A.ESP32:

The ESP32 microcontroller serves as the central processing unit of the GramBox X system. It coordinates all hardware components, processes data, and communicates with Firebase for data storage and retrieval. With its dual-core processor, built-in Wi-Fi, and Bluetooth capabilities, it efficiently handles multiple operations like attendance logging, voting data transfer, and voice announcements simultaneously. The ESP32's multiple GPIO pins make it ideal for connecting peripherals such as RFID, LCD, buttons, and sensors, while its low power consumption ensures reliable operation even in solar-powered conditions

Fig 4 ESP32

B. RFID Reader and Cards:

The RC522 RFID reader is responsible for automated attendance tracking. It operates at 13.56 MHz and reads the unique ID stored on RFID cards or tags assigned to each villager. When a card is tapped on the reader, the ESP32 records the user's ID, date, and time into the system, ensuring accuracy and transparency. This touchless technology improves efficiency and hygiene during attendance collection. Each villager or official receives an RFID card, making the process simple and quick during community meetings.

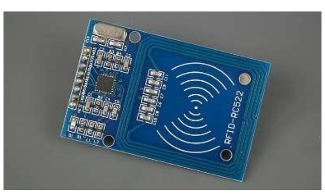

Fig 5 RFID

C. DFPlayer Mini and Speaker

The DFPlayer Mini module handles all voice announcements in the GramBox X system. It stores pre-recorded Tamil audio files on a microSD card and plays them when triggered by the ESP32. These audio messages

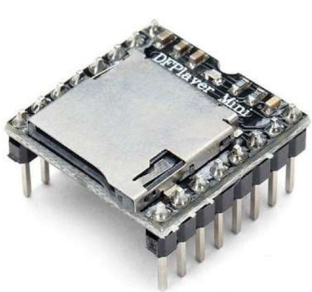

Fig 6 DFPlayer

include notifications like "Attendance recorded," "Voting started," or "Voting completed." The module is connected to an 8-ohm speaker through a small amplifier, providing clear and loud sound output even in open spaces. This ensures that every villager, including those with limited literacy, can understand system prompts easily.

D. MicroSD Card Module

The microSD card module provides non-volatile storage for the system, ensuring all important data such as attendance logs, vote counts, project proposals, and announcements are securely saved. It uses SPI communication with the ESP32 for fast read/write operations. The SD card also holds audio files for the DFPlayer Mini. This storage capability enables offline data recording, allowing the system to work efficiently even without internet access. Data can later be reviewed or transferred for analysis and reporting.

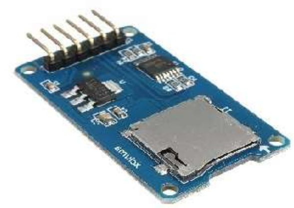

Fig 7 SD module

E. LCD Display (16x2 I2C)

A 16x2 character LCD with an I2C interface is used to display essential information like current date, proposal name, voting instructions, and results. The I2C communication reduces the number of pins required, allowing other modules to connect easily to the ESP32. The bright backlight and adjustable contrast ensure clear visibility in both indoor and outdoor environments. During voting sessions, the LCD provides real-time feedback, making the process more transparent and interactive for villagers.

Fig 8 LCD

F. *Voting Buttons (YES/NO)*

Two large push buttons labeled "YES" and "NO" are provided for villagers to cast their votes easily. These tactile switches are connected to the ESP32 through GPIO pins and use pull-up resistors to prevent false triggering. Each button press is registered only once using debounce logic in software. The use of physical buttons makes the system simple for all age groups, especially those unfamiliar with touchscreens or digital devices.

Fig 11 Button

G. Speaker and Amplifier

The speaker system, driven by a small PAM8403 amplifier, plays all voice announcements generated by the DFPlayer Mini. It ensures that instructions and alerts reach everyone in a public setting. The amplifier boosts the signal to deliver loud, distortion-free audio through an 8-ohm speaker. The clear voice output is particularly useful in large halls or outdoor Gram Sabha meetings, ensuring inclusiveness and accessibility for all participants, including elderly villagers.

Fig 9 Speaker

H. Real-Time Clock (DS3231)

The DS3231 Real-Time Clock (RTC) module maintains accurate timekeeping for the system. It ensures that attendance, voting, and data logging happen with correct timestamps. The module has a built-in temperature-compensated crystal oscillator, providing high precision with minimal drift. It operates through I2C communication and includes a backup coin cell battery (CR2032) that keeps time even when the main power is disconnected. This feature is crucial for maintaining record accuracy during power interruptions or solar recharging cycles.

I. Solar Power System

The solar power system enables the GramBox X to operate independently in rural areas without stable electricity. It includes a solar panel, charge controller, and rechargeable battery. The solar panel converts sunlight into electrical energy, which is managed by the charge controller to safely charge the battery. The stored power runs the entire setup, including ESP32, LCD, and audio modules. This renewable energy design supports sustainable operation and aligns with eco-friendly village development initiatives.

Fig 10 Solar Power

J. Power Regulator (Buck Converter)

The buck converter or voltage regulator ensures that each component receives a safe and stable voltage supply. Since the battery or solar output is around 12V, the converter steps it down to 5V and 3.3V levels required by modules like ESP32, RFID, and SD card. Proper voltage regulation prevents overheating, short circuits, and damage to sensitive electronics. Using efficient DC-DC converters also reduces energy waste and extends battery life, making the system reliable for long-term outdoor use.

K. Voice Recorder Module

The voice recorder module (ISD1820) is used for recording complaints or feedback directly from villagers. It allows short voice clips to be stored on the SD card for review by the Gram Sabha or government officials. The recorder is easy to operate using a single record and playback button. This feature promotes inclusive communication, ensuring even those who cannot write can express their opinions or raise issues.

L. Wiring and Connectors

High-quality jumper wires, screw terminals, and connectors are used to link all components neatly and securely. Proper color coding (red for power, black for ground) avoids confusion during maintenance. The use of soldered joints or terminal blocks ensures strong connections that can withstand vibrations and outdoor conditions. Organized wiring improves the reliability and safety of the system.

M. Enclosure Box

All components are housed in a sturdy, weatherproof ABS or metal enclosure. It protects the electronics from dust, moisture, and physical damage. The enclosure has slots for the LCD, RFID reader, and buttons, making it user-friendly and easy to access. Proper ventilation and cable management inside the box ensure long-term durability and professional appearance during public demonstrations or field installations

IV. Software Requirements

A. Arduino IDE :

The Arduino Integrated Development Environment (IDE) is the central software platform used for programming and debugging the ESP32 microcontroller in the GramBox X system. It provides all essential tools required for writing, compiling, and uploading the firmware directly to the hardware. The IDE supports multiple programming languages such as C and C++, making it suitable for embedded and IoT-based applications.One of the key advantages of the Arduino IDE is its simplicity and flexibility. It includes a built-in code editor, compiler, and serial monitor, which help developers test, modify, and debug the program efficiently. During the development phase of GramBox X, the IDE was used to verify module connections such as the RFID reader, SD card, DFPlayer Mini, and LCD display by viewing live data outputs in the serial monitor window. This allowed accurate testing of attendance scanning, button responses, and data storage before field deployment.The IDE also provides a vast collection of open-source libraries that simplify communication with external modules. By importing these libraries, developers can easily integrate peripherals like the RTC (Real-Time Clock), SD card, and audio module without writing low-level code. This reduces development time and ensures code reliability.Unlike traditional operating systems or web-based environments, the Arduino IDE does not require internet connectivity to execute or manage programs. Once the firmware is uploaded to the ESP32, the device can run autonomously in a completely offline environment.

B. ESP32 Board Support Package :

The ESP32 Board Support Package (BSP) is a crucial software layer that enables the Arduino IDE to communicate directly with the ESP32 microcontroller hardware. It includes all the necessary drivers, configuration files, and compiler settings that allow the IDE to recognize and program the ESP32 board. Without this package, the development environment would not be able to compile or upload code properly to the device.In the GramBox X system, the BSP ensures smooth integration between the software environment and the ESP32 hardware. It provides low-level support for essential functions such as GPIO handling, PWM signal generation, UART communication, SPI and I²C interfacing, and Wi-Fi initialization (used only for local communication if needed). Through this package, developers can use standard Arduino functions (like digitalWrite(), analogRead(), and Serial.begin()) to control the ESP32 without needing to write complex hardware-level code.The BSP also includes firmware libraries that enhance the performance and stability of the ESP32. It manages memory allocation, interrupt handling, and peripheral communication, which are all essential for multi-module integration in GramBox X. For example, it ensures that the ESP32 can efficiently communicate with the RFID reader through SPI, with the LCD and RTC using I²C, and with the DFPlayer Mini through UART—all simultaneously and without interference.

During development, the BSP allows the user to select the correct board type (e.g., “ESP32 Dev Module” or “NodeMCU-32S”) from the Arduino IDE’s board manager. It automatically adjusts parameters such as flash memory size, clock speed, and serial baud rate to match the hardware specifications. This flexibility ensures that the compiled program is fully optimized for the chosen ESP32 variant, improving execution speed and reducing power consumption.

C. Embedded C++ Programming Language :

The GramBox X firmware is developed using Embedded C and C++, which are widely used for microcontroller-based applications due to their efficiency and low-level hardware control. These languages allow direct manipulation of GPIO pins, timers, interrupts, and memory, enabling precise control over the ESP32’s operations. Using C/C++ ensures that all tasks—such as reading RFID tags, recording votes, updating LCD displays, controlling audio playback through the DFPlayer Mini, and writing data to the SD card—execute with minimal delay and predictable timing. The structured nature of C/C++ allows modular code development, making it easier to manage complex system logic like event-driven attendance, sequential voting, and synchronized voice announcements. Moreover, these languages are memory-efficient, which is crucial for embedded systems with limited RAM and flash storage. They provide access to standard libraries as well as third-party Arduino libraries for peripheral integration. In the offline GramBox X system, C/C++ ensures reliable performance without relying on external operating systems, web servers, or internet connectivity. The choice of these languages also allows future enhancements, such as integrating GSM modules, Bluetooth communication, or additional sensor modules, without major code restructuring.

D. Offline Database

Since GramBox X is designed to operate fully offline, all critical data such as attendance records, voting results, and system logs are stored locally on the device. This is achieved using SD card storage, which allows the system to maintain text or CSV files containing attendance sheets, vote counts, and proposal information. The SD card provides ample memory for long-term storage and enables easy retrieval and backup of records. Additionally, small amounts of persistent data, such as device configuration and last known system states, are stored directly on the ESP32’s EEPROM, ensuring that essential information is retained even during power interruptions. By relying on local storage, the system remains secure and tamper-resistant, while also allowing data to be transferred manually to a PC for reporting or analysis. The combination of SD card and EEPROM storage ensures that GramBox X functions reliably in areas with limited or no internet connectivity, while providing an organized and accessible way to manage records.

E. Local User Interface for Offline Operation

The GramBox X system incorporates a user-friendly local interface to facilitate smooth operation during Gram Sabha meetings. This interface, displayed on the connected LCD or OLED screen, allows organizers to manage attendance, voting, and announcements without relying on external servers or cloud platforms. Users interact with the system through physical buttons or a simple touchscreen, depending on the hardware setup, ensuring accessibility for people of all technical levels. Clear visual prompts guide the user through each process, such as starting attendance, casting votes, or reviewing results, minimizing the risk of errors. The interface also provides real-time feedback, displaying messages like “Vote Recorded” or “Attendance Marked” to confirm actions. By keeping the interface entirely offline, GramBox X ensures operational reliability even in remote village locations, while maintaining ease of use, efficiency, and clarity for administrators and participants alike.

F. Data Storage and Management

The system requires a reliable method to store and manage all data locally without depending on an online server. This includes storing user details, attendance records, voting results, and sensor data securely in local memory or databases such as SQLite or local JSON/CSV files. The software should allow easy retrieval, updating, and backup of data while ensuring integrity and minimal risk of corruption. Efficient data handling is crucial to maintain smooth system performance during real-time operations.

V. Software Implementation

The software implementation of GramBox X focuses on providing a seamless, reliable, and user-friendly interface for managing smart village operations. The system is primarily developed using Arduino/ESP32 IDE for microcontroller programming, with C++ code handling sensor interfacing, RFID/QR-based attendance, SD card data logging, and voting button inputs. The ESP32 firmware manages real-time communication with Firebase, allowing secure storage and retrieval of attendance records, voting results, and project notifications. The voice assistant module is implemented to provide audible notifications and instructions during attendance, voting, and announcement phases. Text-to-speech algorithms are embedded within the ESP32, allowing offline operation without dependency on web servers. The LCD display is controlled via I2C communication, presenting real-time information such as voter confirmation, project statuses, and announcements to ensure clarity and accessibility for villagers. For data storage and logging, SD card modules are integrated, enabling offline data backup and retrieval in case of network issues. The software is designed with modular functions for each hardware component, ensuring maintainability and easy scalability. Error handling routines are incorporated to manage potential hardware faults, network failures, or incorrect input scenarios.

VI. Result & Discussion

The GramBox X – Smart Village IoT Hub was implemented and tested to evaluate its efficiency, reliability, and usability. The automated attendance module, which uses RFID/QR scanning, successfully recognized each villager and updated the attendance records both on the local SD card and the Firebase database in real-time. The average recognition delay was less than one second, demonstrating the system's responsiveness. No missed scans were reported, and the SD card logs provided a reliable offline backup for historical data. The voting module, which uses YES/NO buttons for fund proposals, recorded votes accurately and updated the Firebase database simultaneously. The results were clearly displayed on the LCD and announced through the voice assistant, ensuring accessibility for all villagers, including those unfamiliar with digital interfaces. The system handled simultaneous attendance recording and voting without any loss of data, and the synchronization between the ESP32, Firebase, LCD, and voice assistant remained consistent, with delays of less than half a second. The SD card module reliably stored all attendance and voting data in text files, which were easily retrievable for analysis. This local storage reduces dependency on continuous internet connectivity and provides a secure backup for the village records. The LCD display and voice assistant effectively communicated updates in real-time, enhancing transparency and participation during Gram Sabha meetings. Overall, the GramBox X system demonstrated high accuracy, responsiveness, and reliability across all modules, with an overall operational accuracy of 99–100%. Minor delays observed during simultaneous operations suggest potential areas for optimization in data handling and microcontroller processing. The system's modular design ensures scalability. for future enhancements, making it a robust solution for smart village management by combining automation, accessibility, and transparency in governance processes.

VII. Conclusion

The GramBox X – Smart Village IoT Hub successfully integrates multiple technologies to streamline village administration and enhance community participation. The system effectively automates attendance tracking, securely records voting results for fund proposals, and communicates updates through both LCD displays and a voice assistant, ensuring accessibility for all villagers. Testing showed that the modules—including RFID/QR attendance, SD card logging, voting buttons, and real-time Firebase synchronization—performed with high accuracy and reliability, even in offline conditions, making the system resilient to network interruptions.The project demonstrates how IoT-based solutions can modernize traditional governance processes, promoting transparency, efficiency, and accountability. The modular architecture allows for easy expansion, such as adding more sensors, voice-assisted services, or data analytics capabilities in the future. Overall, GramBox X represents a practical, scalable, and user-friendly approach to smart village management, providing a foundation for further innovations in rural technology adoption and community-driven development.

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